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GB 2088077 A GB 1274875 A GB 0808764 A

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UK CL (Edition J) G2F FCH, H2A AGA AGE AGH AGL
INT CL⁴ H02N

(54) **Liquid displacement**

(57) A fluid 2, preferably a liquid and most especially liquid crystal, is displaced by applying an electric field across its surface, using the Maxwell-Faraday effect, bulk displacement of the fluid from reservoir 1 being achieved by using a pair of electrodes 3 of appropriate length which also serve to guide the displaced fluid. A pumping action is possible by appropriate control of a potential difference applied across the electrodes (Fig. 3 not shown). An alternative embodiment (fig. 2 not shown) uses displaced fluid to operate piston pins in a brail reading machine.

FIG 1A

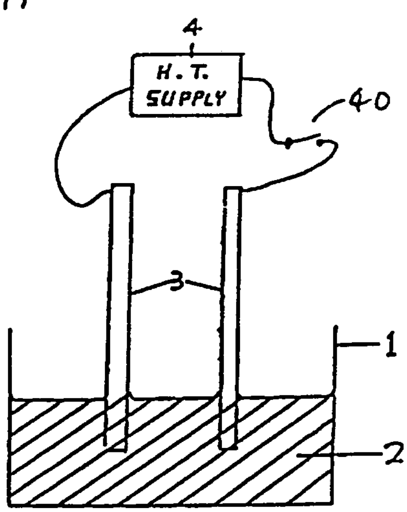

FIG 1B

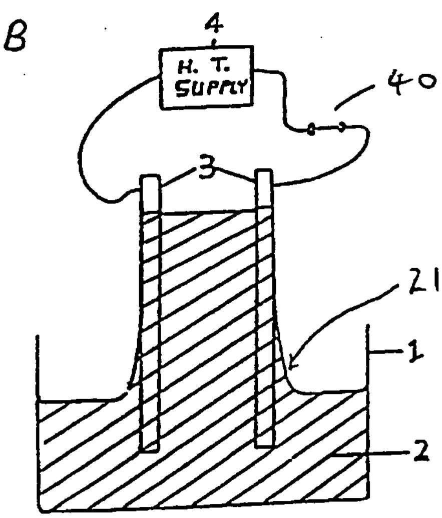

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FIG 1A

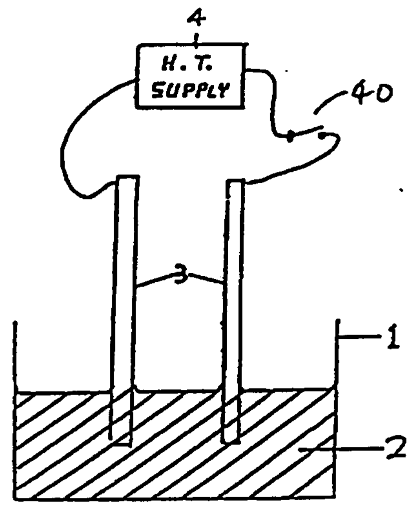
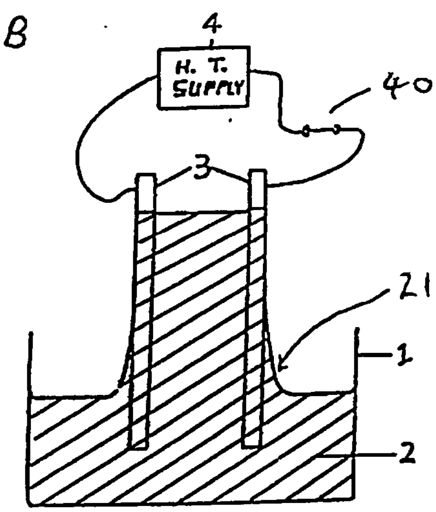


FIG 1B



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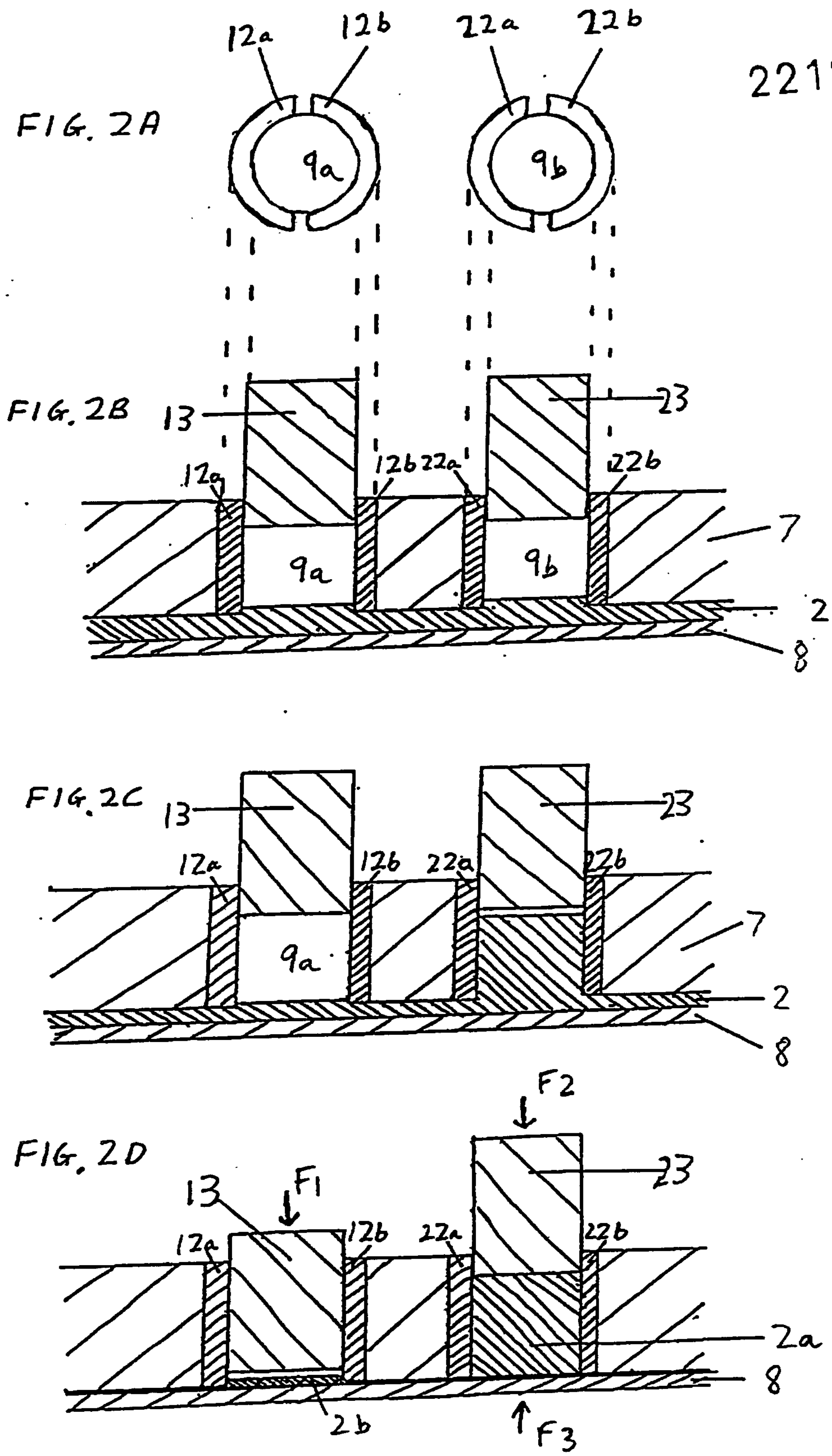


FIG. 2A
12a
12b
22a
22b
9a
9b
FIG. 2B
13
23
12a
12b
22a
22b
7
2
8
FIG. 2C
FIG. 2D
F1
F2
F3
2a
2b

FIG 3A

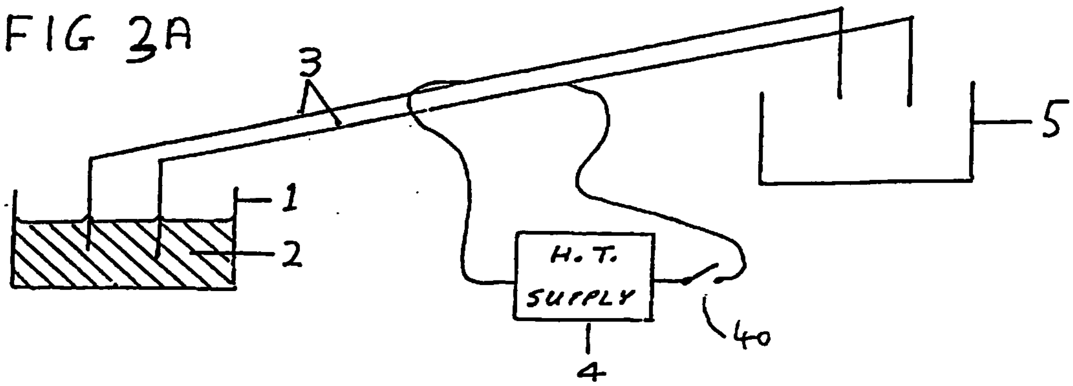


FIG 3B

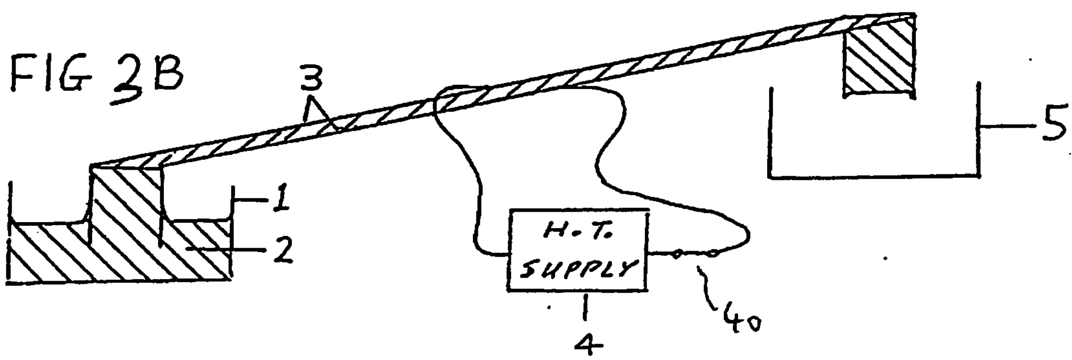
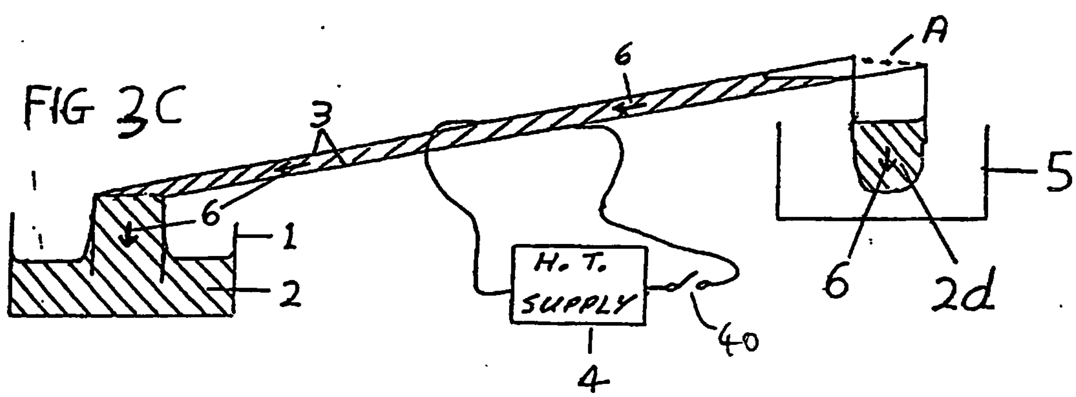


FIG 3C



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Fluid Displacement

This invention relates to a method and apparatus for the displacement of a fluid; in one aspect, it concerns the bulk displacement of any fluid, and in a further aspect it concerns the displacement of liquid crystal in particular.

The movement of a fluid by the application of an electric field is known from European Patent Application No. 131493A, in which fluid globules are contained in a capillary space of uniform height between two confining plates. The fluid globules are induced to move selectively towards and away from the region between a pair of electrodes carried by the plates, by the application of a potential difference across the electrodes. The attraction of the fluid globule towards the electrodes is due to forces produced by the electrical polarisation of the fluid elements (which is due in turn to the electric field gradients), the forces arising because the fluid globules have a greater electrical permittivity than that of the medium between the electrodes and surrounding the fluid globules. This effect has been termed the Maxwell-Faraday effect. The fluid globules constitute the moving part of an optical switch, in which the surfaces of the confining plates have to be specially treated. The apparatus and process

disclosed in that published specification are not capable of causing bulk displacement of a fluid.

Accordingly, the invention provides apparatus for the bulk displacement of a fluid, comprising a reservoir for the fluid, means for guiding the fluid from the reservoir along a predetermined path to a region outside the reservoir, and means for applying selectively an electric field across that portion of the fluid surface which is to follow the path, the electric field having a component perpendicular to the direction of the path, whereby selectively to displace the fluid along the path from the reservoir.

The invention thus provides for the bulk displacement of a fluid without the need for mechanical action.

Liquid crystal is a particularly useful fluid in certain electrical applications, and it has fortunately been discovered that liquid crystal is displaced particularly readily upon the application of an electric field.

Thus, according to a further aspect, the invention provides apparatus comprising a reservoir containing liquid crystal, and means for applying selectively an electric field in a region including a portion of the surface of the liquid crystal, whereby to displace the liquid crystal generally perpendicularly to that portion of the surface and away from the reservoir. The apparatus preferably comprises means for guiding the liquid crystal

from the reservoir along a predetermined path to a region outside the reservoir, the electric field having a component perpendicular to the path whereby to displace the liquid crystal along that path.

According to a further aspect, the invention provides a method of displacing liquid crystal by applying an electric field across its surface.

Several fluids, in addition to liquid crystal, have been tested for their susceptibility in this way to an applied electric field, and effects have been found with water and with glycol, which are known to have high dielectric constants. The phenomenon is not clearly understood, but is believed to be the result, at least in part, of the so called Maxwell-Faraday effect. In the case of liquid crystal, the phenomenon is so strong that it resembles, on a much larger scale, the effect of capillary action. It is possible that a contributory effect is that the surface tension of the liquid crystal undergoes a substantial change when the applied electric field changes.

Further, it is known that electro-rheological fluids, in particular, have potential applications in control systems and actuating systems, as disclosed for example in our co-pending UK Patent Application No. 8711542 (Publication No.). Fortunately, such fluids, including liquid crystal, generally demonstrate, at least

to some extent, the effect of displacement in accordance with the invention.

Finally, according to a further aspect of the invention, a method for the bulk displacement of a fluid from a reservoir to a region outside the reservoir along a predetermined path comprises selectively applying and maintaining an electric field across that portion of the fluid surface which is to follow the path, and guiding the fluid along the path. The fluid may be a liquid crystal, and may be electro-rheological. In the case of an electro-rheological fluid, the method preferably includes the step of increasing the applied electric field so as to solidify the fluid to maintain it at its displaced position.

Some of the ways in which the invention may be performed will now be described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1a is a diagrammatic elevation of apparatus according to a first embodiment of the invention;

Figure 1b is an elevation corresponding to Figure 1a and illustrating the effect of an applied electric field;

Figures 2B, 2C and 2D are diagrammatic sections, taken along the axis, of part of a pin-actuating machine embodying the invention, illustrating successive stages of its operation, and Figure 2A is a top plan view of part of the machine of Figures 2B, 2C and 2D; and

Figures 3a, 3b and 3c are diagrammatic perspective views of apparatus according to a third embodiment of the invention, constituting a fluid pump, the figures illustrating different stages of operation of the pump.

With reference first to Figures 1a and 1b, a reservoir 1 is partially filled with a liquid 2 and is open at the top. A pair 3 of parallel plate electrodes is supported vertically so that the lower ends of the electrodes are immersed in the liquid 2. The electrodes 3 are connected by way of a switch 40 to a high tension (H.T.) supply 4.

The electrodes 3 together define a vertical path extending vertically away from the reservoir 1, and also constitute means for guiding the liquid 2 along that path. The electrodes are separated by several millimetres and may be anything from about 1mm to several centimetres wide and several centimetres high.

The voltage supplied by the H.T. supply 4 is in this example 1kV, but could take any value, in accordance with the electrode separation, sufficient to cause the desired displacement of the fluid but insufficient to cause arcing across the air.

In the absence of any applied potential difference across the electrodes 3, as shown in Figure 1a with the switch 40 open, there is no displacement of the liquid 2 from its rest position with a generally horizontally surface. When a potential difference is applied, however,

as shown in Figure 1b with the switch 40 closed, a film of the liquid 2 rises along the path vertically between the electrodes 3. A wide meniscus 21 also appears where the generally horizontal surface of the liquid 2 is in contact with the electrodes 3. This effect is particularly marked where the liquid 2 is liquid crystal.

When the voltage supplied by the HT supply 4 is increased yet further, in the case of an electro-rheological fluid such as liquid crystal the portion of liquid suspended above the remainder of the liquid 2 is frozen and maintained at that position until the applied potential difference is once again reduced.

One possible application of the phenomenon demonstrated with reference to Figures 1a and 1b is in a modification of the pin-actuating machine disclosed in our copending U.K. Patent Application No. 8711542 (Publication No.) to which reference has already been made. That application discloses a pin-actuating machine which consists of a metal block having multiple axial bores each having a metallic actuator pin disposed for axial movement and insulated from the bore. The inner wall of each bore and its corresponding pin constitute a pair of cocentric, parallel conductors. The block is supported with an axial end region immersed in an electro-rheological fluid contained in a reservoir. An electric field is generated between selected pins and the metal block to cause the

fluid which fills the gaps in the bores to solidify, thus preventing the selected pins from being displaced from their initial positions. If a large enough force is applied, however, the solidified fluid will break down and allow even the selected pins to be displaced. This drawback may be overcome by employing the present invention.

This second embodiment of the invention will now be described with reference to Figures 2a to 2d. A metal or plastics block 7 has a multiplicity of parallel bores, of which two, 9a and 9b, are shown. These bores define fluid chambers which are normally in free communication with a reservoir, disposed beneath the block 7 but not shown, of a liquid 2 which could be any liquid which is displaceable under the action of an applied electric field in the manner of the invention. The preferred liquid is liquid crystal: unlike the pin-actuating machine of our co-pending U.K. patent application mentioned above, there is no need for the liquid to be electro-rheological.

Each bore 9a, 9b has a pair of semi-cylindrical, conductive sleeves 12a, 12b; 22a, 22b respectively, as shown in plan view in Figure 2a. These sleeves act as electrodes for applying an electric field transversely of the axis, and are electrically insulated from the block and from each other. The electrodes are connected electrically, by means not shown, to a power supply by way of a control system, whose function will be described

below.

Associated with each bore 9a, 9b is a non-conductive piston 13, 23 respectively, disposed for sealed, sliding motion in the sleeves. The pistons are of course illustrated only diagrammatically, and could for example comprise a piston head connected to an actuating pin of substantially smaller diameter.

A sealing plate 8 faces the lower end face of the block 7 and is moveable, by control means not shown, axially of the block 7 between an open position, shown in Figures 2b and 2c, and a sealing position, shown in Figure 2d, at which it closes the ends of all the bores.

The upper end portion only of each pair of sleeves 12a, 12b; 22a, 22b may be fluted to allow air to escape from the chamber when the piston is at its fully raised position.

In operation, the pistons 13, 23 are raised fully, so that they project from the upper end face of the block 7, as shown in Figure 2b. The chambers 9a, 9b both contain air. Assuming that it is desired to retract piston 13 but to maintain piston 23 at the same position the control system operates to select only the pair of electrodes 22a, 22b, across which a potential difference of 1kV is applied. Under the same mechanism as described above with reference to Figures 1a and 1b, some of the liquid 2 is drawn up into the chamber 9b between the electrodes 22a, 22b, and displaces the air from the chamber (or,

alternatively, simply compresses the air). This stage is shown in Figure 2c. The sealing plate 8 is then raised, under an applied axial force F3, as shown in Figure 2d, to trap the liquid 2a in chamber 9b. A very small amount of the liquid 2b will have entered the other chamber 9a. An axial compressive force F1 acting on piston 13 will move the piston into its fully retracted position, because the air in the chamber is compressible. However, a corresponding force F2 acting on the other piston, piston 23, will be unable to displace the piston, because the liquid 2a is substantially incompressible.

When the sealing plate 8 is lowered once again, the cycle may be repeated, possibly with a different combination of pistons being actuated.

This second embodiment of the invention has a wide range of possible applications, and the number and configuration of the actuating pistons and the nature of the control system may be adapted accordingly. For example, the apparatus could be used in a brail reading machine, in which a line of brail is created electronically by means of a matrix of pins controlled by pistons such as pistons 13, 23. A further application is in a circuit board tester, where electronic probes may be actuated selectively in a predetermined sequence.

Clearly, this actuating apparatus overcomes the drawback described above associated with the pin-actuating machine of our co-pending patent application, because it

is capable of withstanding much greater applied axial forces. Moreover, it does not require the electric field to be maintained once the chambers have been sealed by the sealing plate.

The third embodiment of the invention will now be described with reference to Figures 3a, 3b and 3c.

A liquid pump comprises an open-topped reservoir 1 containing the liquid 2, an empty receptacle 5, open-topped and situated at the same horizontal level, and a pair of parallel, co-extensive wires 3 extending generally horizontally from the reservoir 2 to the receptacle 5. The ends of the wires 3 are bent through a right-angle to a vertical orientation at each end: the ends of the wires are so disposed that they are partially immersed in the liquid 2 in the reservoir 1 but remain above the level of the receptacle 5, for a purpose which will be described below. As in the example described with reference to Figures 1a and 1b, an HT supply 4 is connected by way of a switch 40 across the wires 3 which constitute not only electrodes but also means for guiding the liquid from the reservoir to the receptacle.

One cycle of the pumping action will now be described with reference to Figures 3b and 3c. A potential difference of 1kV is applied across the wires 3 by closing switch 40. The resulting electric field applied across the surface of the liquid 2, i.e. perpendicular to the

direction of the path for the liquid along the wires, causes the liquid to be displaced vertically. The liquid rises between the vertical ends of the wires 3 in a film, and continues its progress horizontally between the wires until it reaches the opposite ends of the wires, as shown in Figure 3b. Provided the potential difference is maintained, the liquid is stable at that position. However, once the applied potential difference is reduced or removed by opening switch 40, as shown in Figure 3c, the film of liquid is broken at the line A and the two portions of the film travel in the directions shown by arrows 6. The smaller portion 2d falls into the receptacle 5, while the larger portion travels in the reverse direction back towards the reservoir 2. The cycle is then repeated, at a sufficiently higher frequency that the liquid does not return completely to the reservoir 2, but sufficiently low that there is time for the smaller portion of 2d of liquid to fall clear of the wires 3 before the potential difference is increased again. This frequency may for example be between 10Hz and 50Hz.

Although the H.T. supply may be D.C., the cyclic pumping action may conveniently be achieved by using an A.C. H.T. supply at the appropriate amplitude and frequency. In the case of a sinusoidal A.C. supply, the liquid film will split along the line A, or near to that line, as soon as the magnitude of the applied voltage falls to below a certain threshold.

It will be appreciated that the pumping action may be reversed by an appropriate displacement of the ends of the electrode wires 3 away from the reservoir 2 and towards the receptacle 5 which will have become full of the liquid 2. Indeed, such displacement of the wires may not be necessary, if the wires are arranged such that when one end is immersed in the liquid the other end is just above the liquid surface, and vice versa.

Although the electrodes in this embodiment of the invention take the form of wires 3, they could alternatively take the form of metallic plates, enabling a greater quantity of the liquid to be held between their surfaces; indeed, the electrodes could take any form to suit the required path taken by the liquid. The electrodes are mounted in or upon non-metallic, insulating materials (not shown in the drawings).

CLAIMS

1. Apparatus for the bulk displacement of a fluid, comprising a reservoir for the fluid, means for guiding the fluid from the reservoir along a predetermined path to a region outside the reservoir, and means for applying selectively an electric field across that portion of the fluid surface which is to follow the path, the electric field having a component perpendicular to the direction of the path, whereby selectively to displace the fluid along the path from the reservoir.

2. Apparatus according to claim 1, comprising a fluid in the reservoir.

3. Apparatus comprising a reservoir containing liquid crystal, and means for applying selectively an electric field in a region including a portion of the surface of the liquid crystal whereby to displace the liquid crystal generally perpendicularly to that portion of the surface and away from the reservoir.

4. Apparatus according to claim 3, comprising means for guiding the liquid crystal from the reservoir along a predetermined path to a region outside the reservoir, the electric field having a component perpendicular to the path whereby to displace the liquid crystal along that path.

5. Apparatus for pumping liquid, comprising a reservoir for the liquid and a receptacle, a pair of electrodes so disposed in relation to the reservoir that, in use, they

are partially immersed in the liquid, the electrodes extending to the receptacle, and means for applying selectively a potential difference across the electrodes whereby to displace the liquid from the reservoir along a path defined by the electrodes to the receptacle.

6. Apparatus according to claim 5, wherein the electrodes extend over the receptacle such that, in use, the liquid drawn along the path from the reservoir is allowed to fall into the receptacle upon a reduction in the applied potential difference.

7. Apparatus according to claim 6, comprising means for cyclically increasing and decreasing the applied potential difference such as to cause a corresponding cyclic pumping action of the liquid into the receptacle.

8. A method of displacing liquid crystal by applying an electric field across its surface.

9. A method for the bulk displacement of a fluid from a reservoir to a region outside the reservoir along a predetermined path, comprising selectively applying and maintaining an electric field across that portion of the fluid surface which is to follow the path, and guiding the liquid along the path.

10. A method according to claim 9, wherein the fluid is liquid crystal.

11. A method according to claim 9 or 10, wherein the fluid is an electro-rheological liquid.

12. A method according to claim 8 or 11, comprising increasing the applied electric field so as to solidify the liquid to maintain it at its displaced position.

13. A method according to claim 9, or to any of claims 10 to 12 as appendent to claim 9, wherein the electric field is applied by way of a pair of electrodes partially immersed in the liquid and extending away from the reservoir to define the path and to guide the liquid along the path and between the electrodes.

14. A method according to claim 13, comprising pumping the liquid from the reservoir to a receptacle disposed adjacent to the electrodes remote from the reservoir, by varying the potential difference applied across the electrodes to drive the liquid in a cyclic fashion, each cycle comprising reducing the potential difference to release some of the liquid from the electrodes into the receptacle and then increasing the potential difference to replenish that liquid by drawing further liquid from the reservoir.

15. Actuating apparatus comprising a piston disposed for sealed, sliding motion in a chamber which normally communicates freely with a liquid reservoir and which normally contains a compressive fluid; means for applying selectively an electric field across that portion of the liquid surface in the region of the chamber, the electric field having a component perpendicular to the axis of the chamber, whereby selectively to draw some of the liquid

from the reservoir into the chamber to displace the said compressible fluid; and means for closing the chamber to trap the liquid therein and to resist the sliding motion of the piston in its compressed state.

16. Actuating apparatus according to claim 15, comprising a plurality of such piston-and-chamber arrangements disposed in parallel, and control means for selecting the chamber or chambers across which to apply an electric field whereby to select, upon closure of all the chambers, those pistons which are to be movable and those which are not.

17. Apparatus for displacing a fluid, substantially as described herein with reference to Figures 1a and 1b.

18. Actuating apparatus substantially as described herein with reference to Figures 2A to 2D.

19. Apparatus for pumping a liquid, substantially as described herein with reference to Figures 3a, 3b and 3c.

20. A method of displacing a fluid, substantially as described herein with reference to Figures 1a and 1b of the accompanying drawings.

21. A method of pumping a liquid, substantially as described herein with reference to Figures 3a, 3b and 3c of the accompanying drawings.

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